

Much Ado About Nothing II

Lecture 8 May 31, 2003

Primordial soup

KNOWN INGREDIENTS:

56% QUARKS

16% GLUONS (STRONG FORCE)

9% ELECTRON-LIKE PARTICLES

9% W's AND Z's (WEAK FORCE)

5% NEUTRINOS

2% PHOTONS (ELECTROMAGNETIC FORCE)

2% GRAVITONS (GRAVITATIONAL FORCE)

1% HIGGS BOSONS (???)

SECRET INGREDIENT:

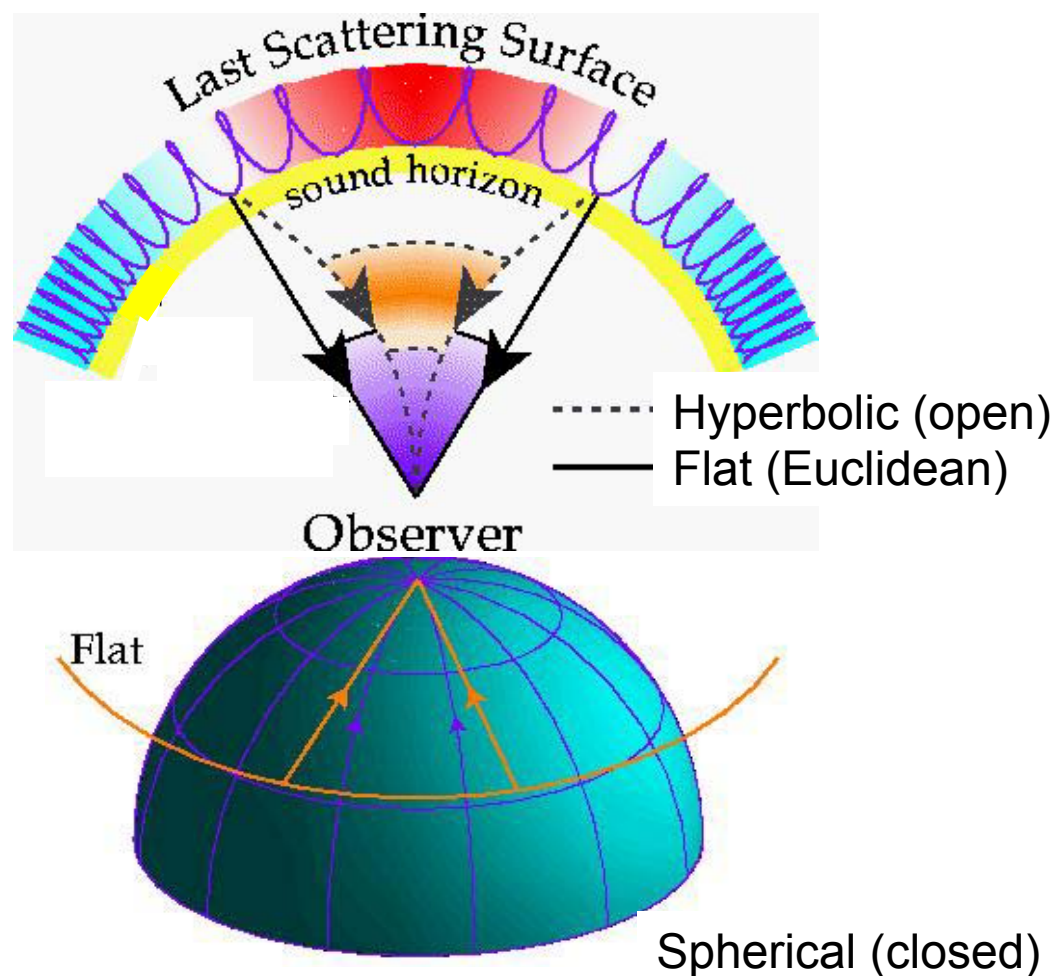
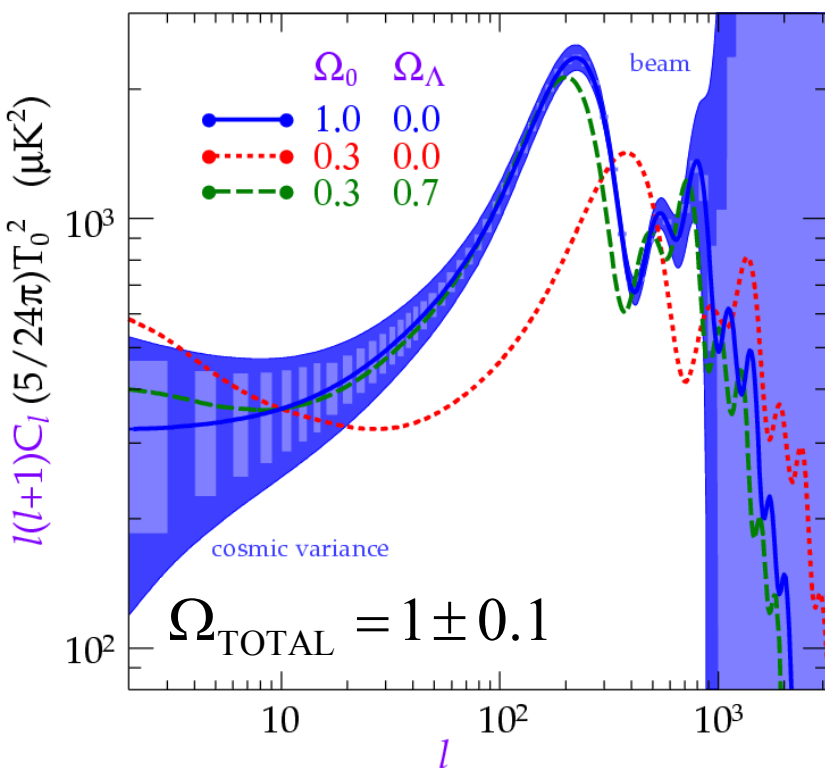
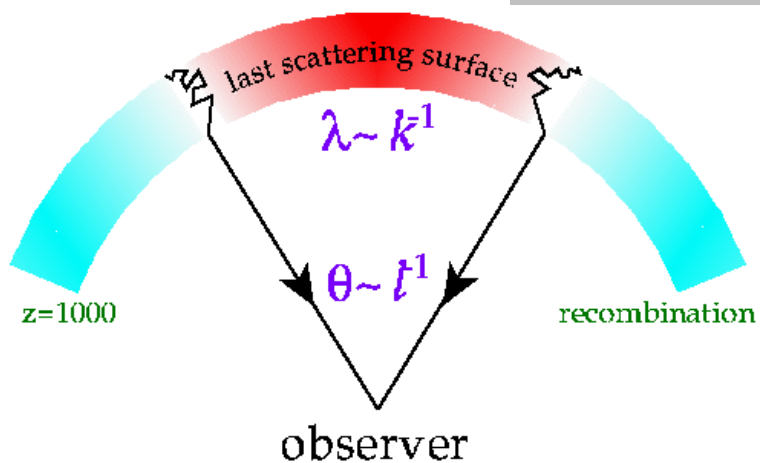
DARK MATTER



Acoustic peaks

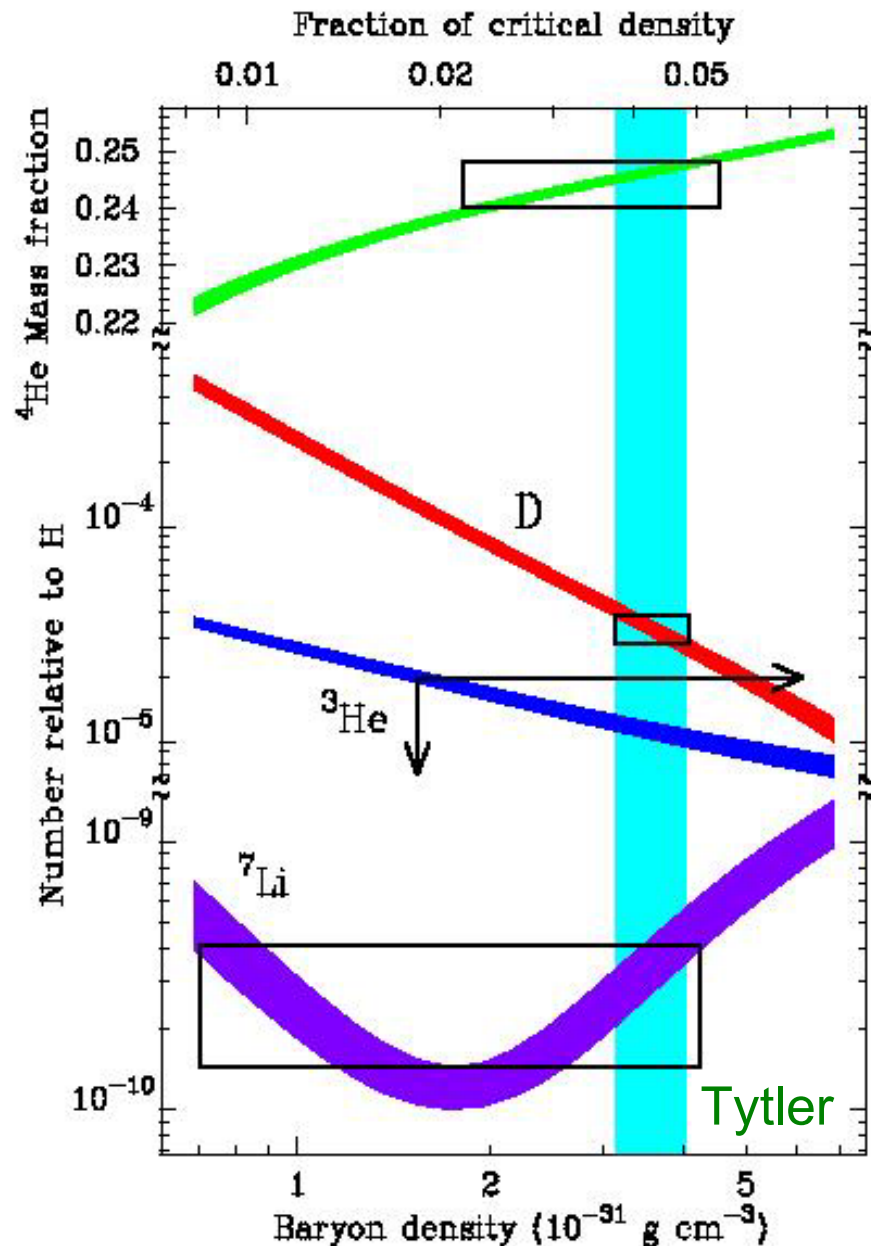
Sound travel distance known

Observed $l_{\text{peak}} \sim \text{geometry}$

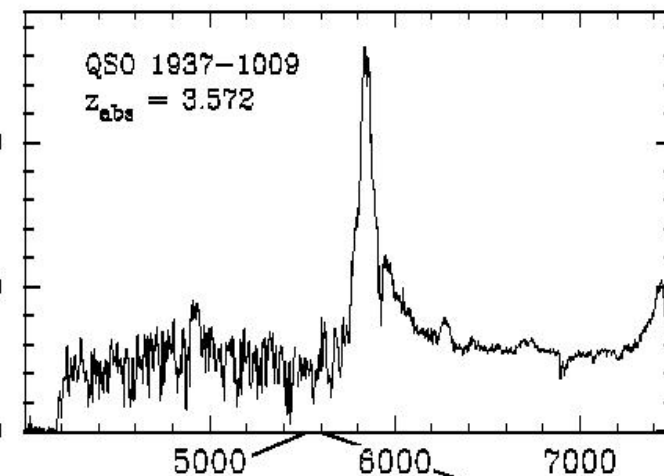


Baryons $\Omega_B h^2 \sim 0.02$ QSO 1937-1009

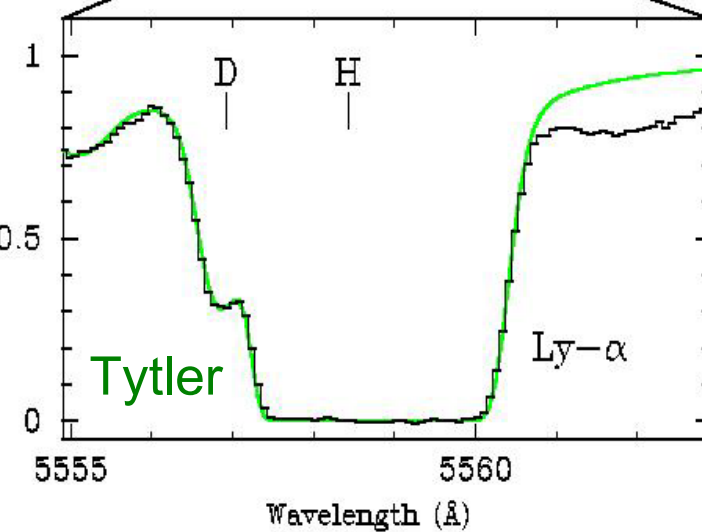
Ly- α



Flux ($10^{-16} \text{ erg s}^{-1} \text{ cm}^{-2} \text{ \AA}^{-1}$)



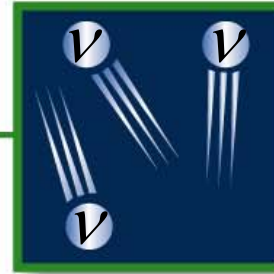
Normalized Flux



Cosmic Pie



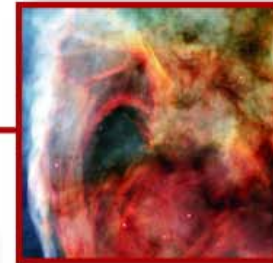
Chemical Elements:
(other than H & He) 0.03%



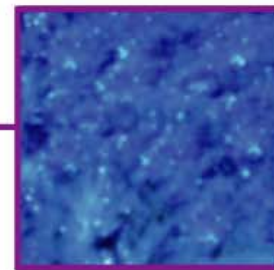
Neutrinos:
0.47%



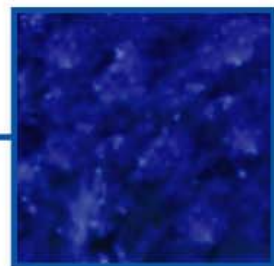
Stars:
0.5%



Free H
& He:
4%

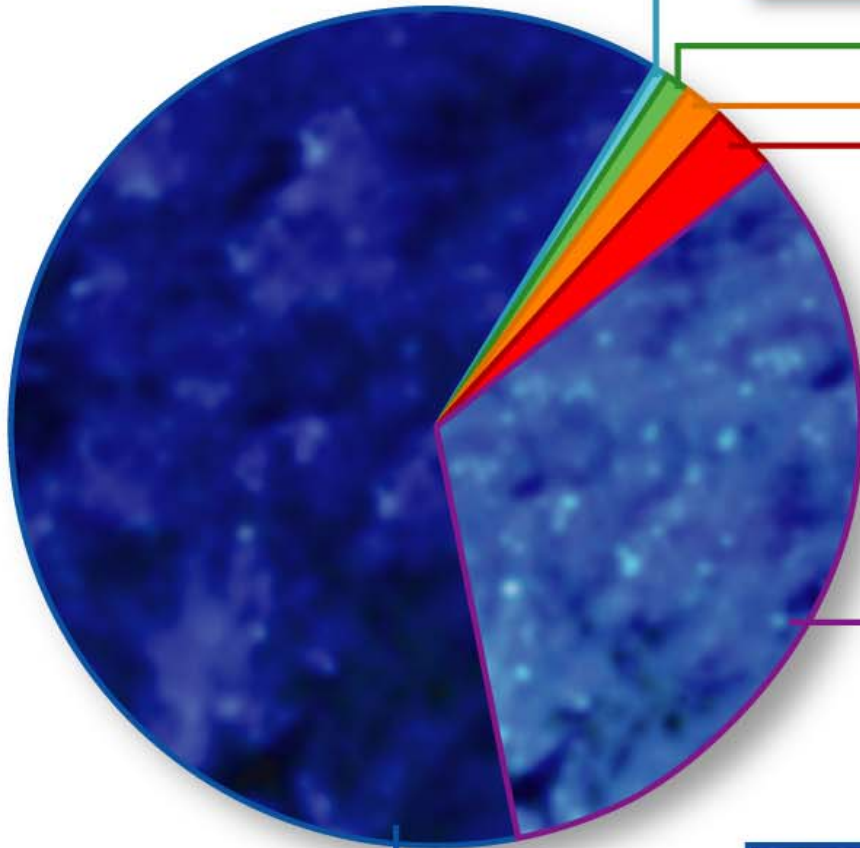


Dark Matter:
25%



Dark Energy:
70%

95%
mystery



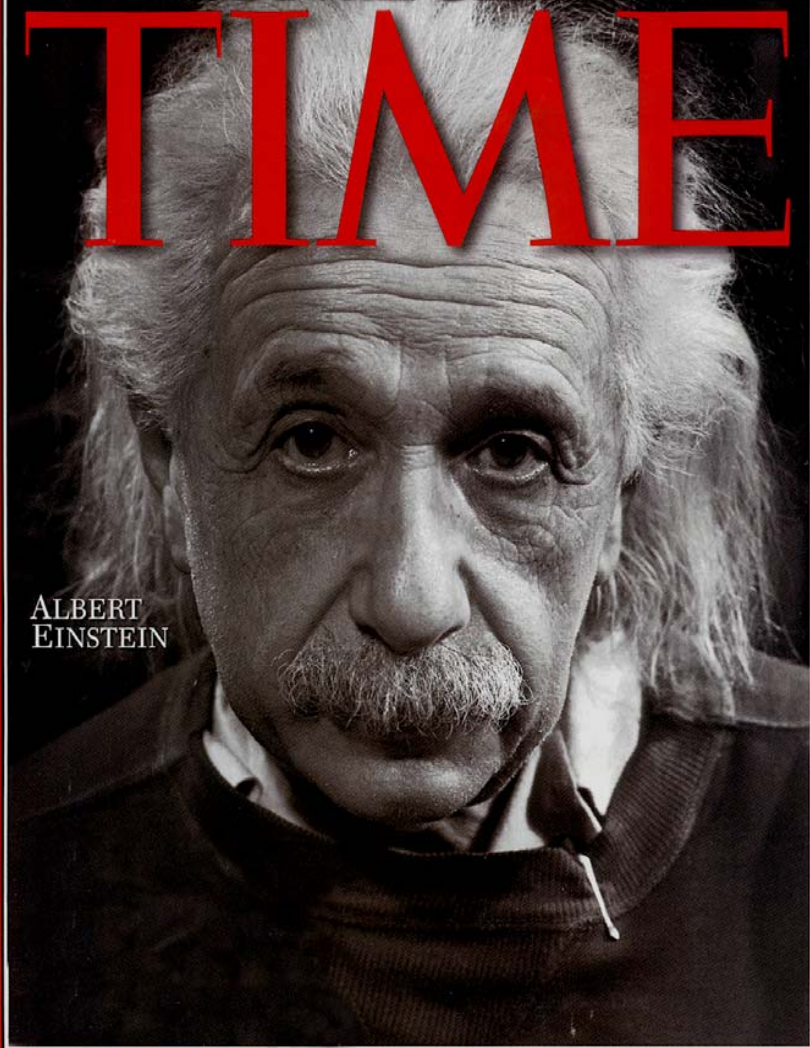
DECEMBER 31, 1999 \$4.95

www.time.com

PERSON OF THE CENTURY

TIME

ALBERT
EINSTEIN



DECEMBER 31, 2000 \$4.95

www.time.com

PERSON OF THE CENTURY

TIME

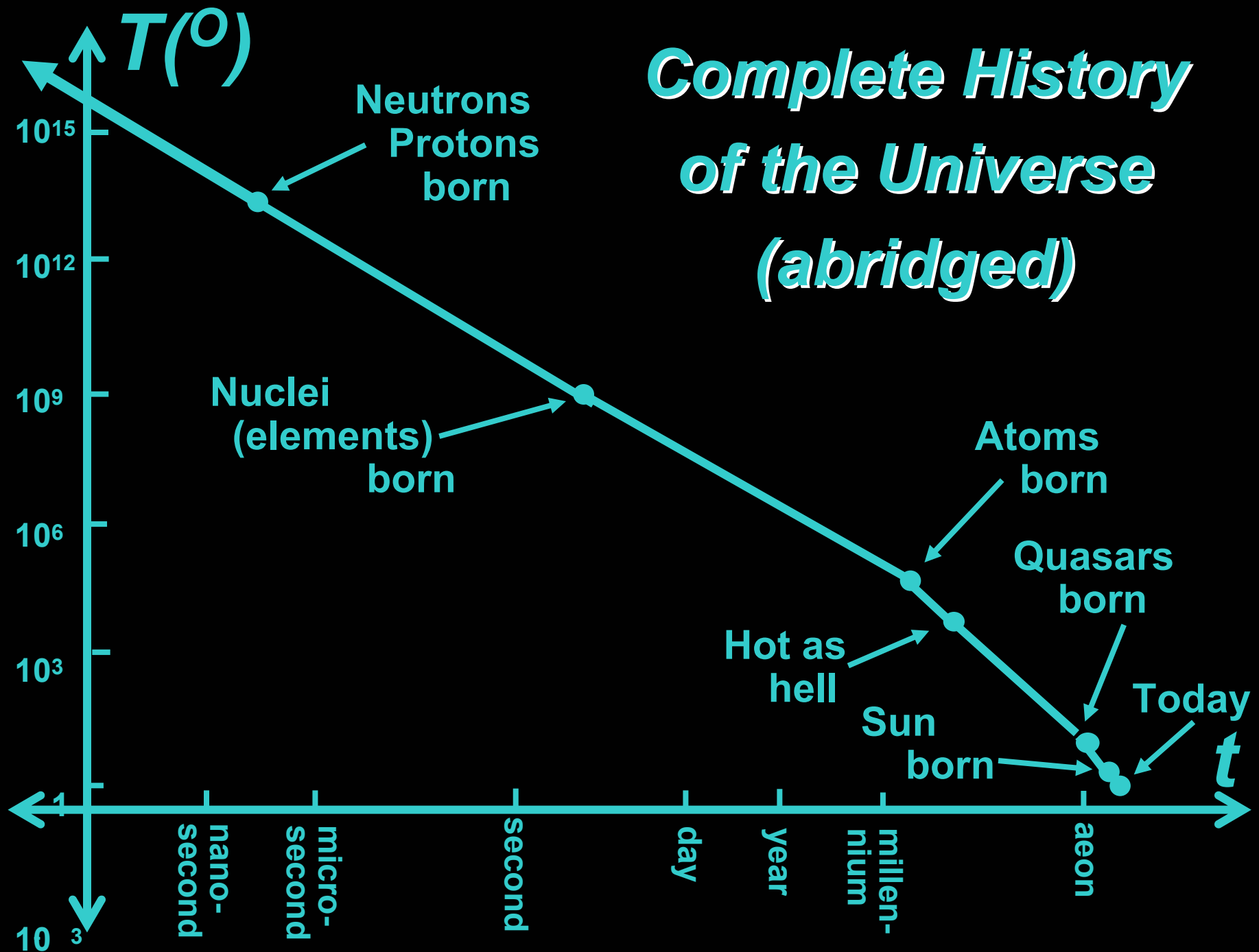
?



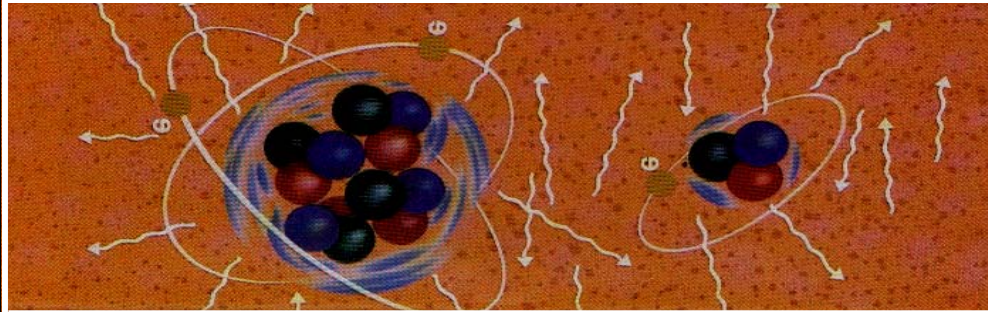


human curiosity

Complete History of the Universe (abridged)

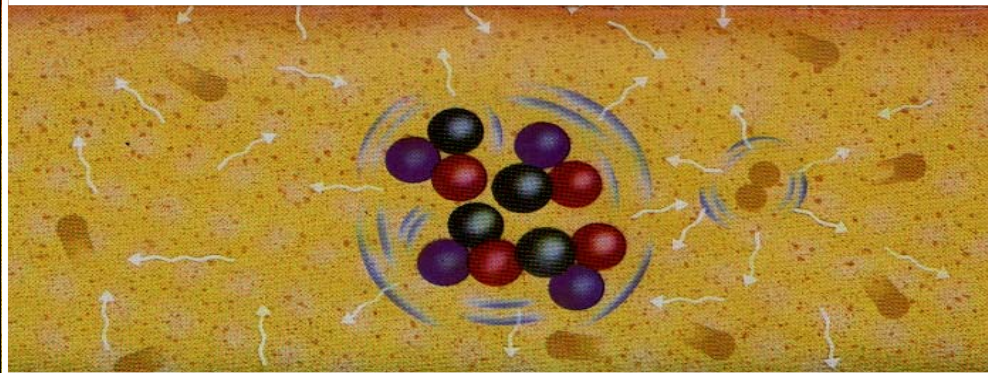


**300,000
years**



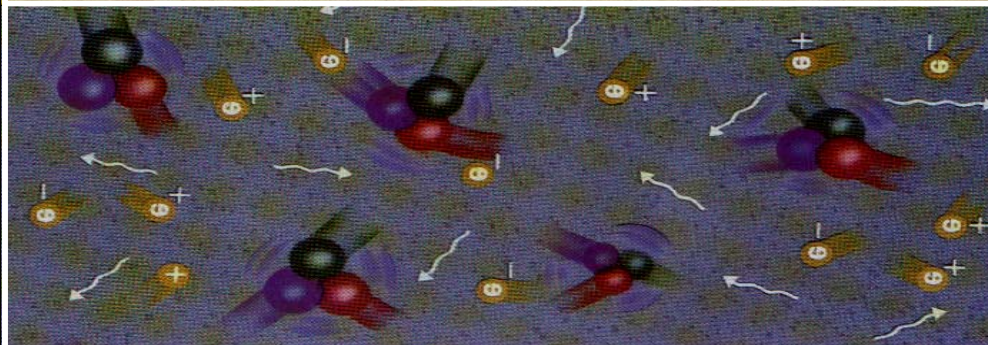
**atoms
form**

**3
minutes**



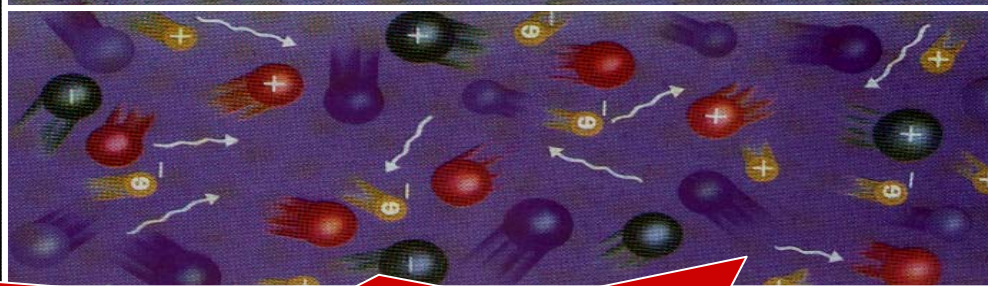
**nuclei
form**

**1-micro
second**



**neutrons
protons
form**

**4-pico
seconds**



**primordial
soup**

BANG!

HORS D'OEUVRES ***BEFORE SOUP ?***

At time zero:

infinite temperature
infinite pressure
infinite density
infinite curvature

At time zero:

spacetime singularity
physical law breaks down
no predictions possible
here be dragons!

BEFORE PRIMORDIAL SOUP ?

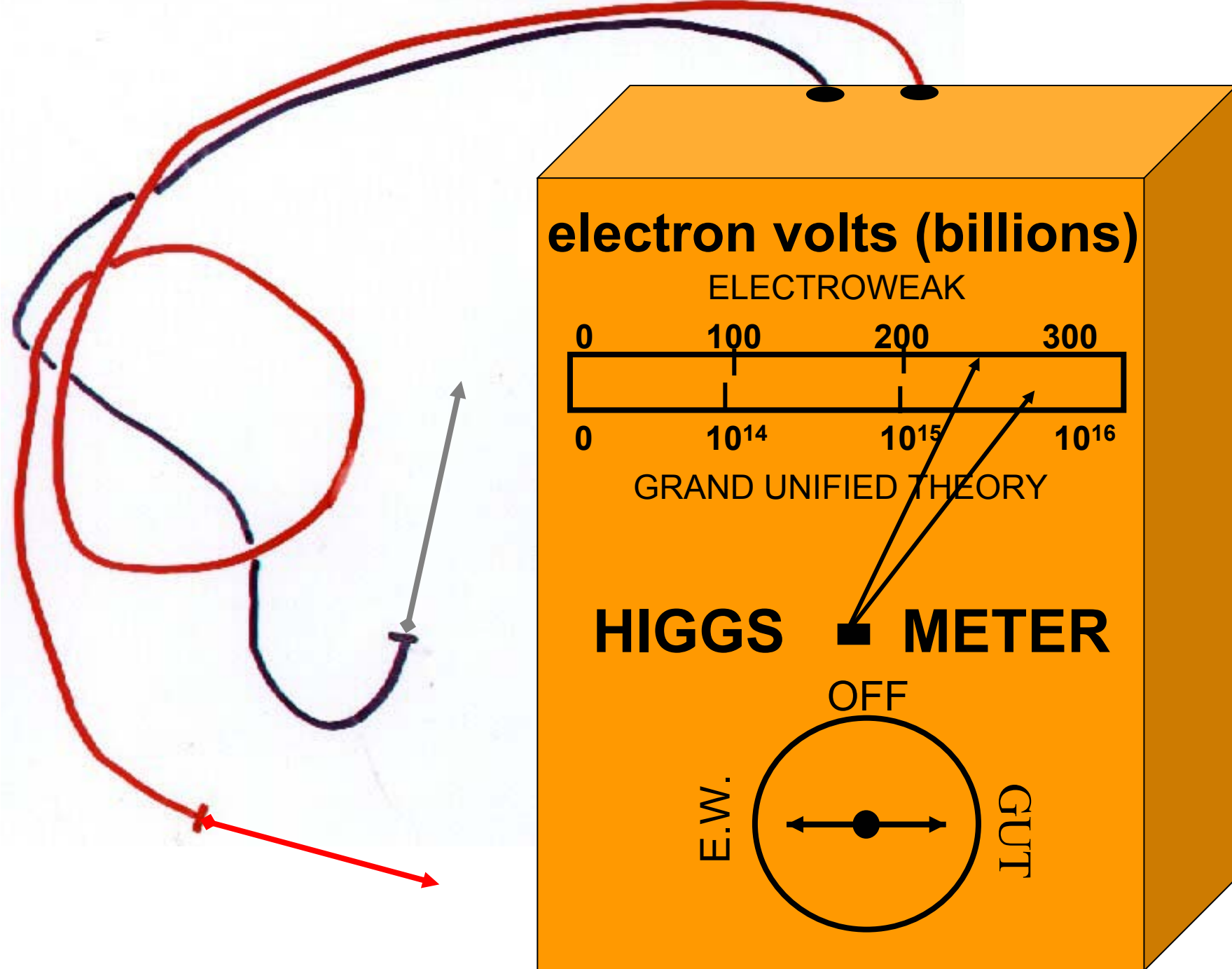
NOTHING!!! (vacuum)

Nothing can change

Today the density of nothingness is less than 10^{-30} grams per cc

Before primordial soup the density of nothingness may have been larger than 10^{+30} grams per cc

The primordial soup came from vacuum discharge (inflation)



Cosmic Symphony (Harmonice Mundi)

tempo	movement	epoch	relic
pizzicato	string dominated	10^{-43} sec. ?	???
prestissimo	vacuum dominated (inflation)	10^{-35} sec. ?	temp. fluctuations, gravitational waves, seeds of structure
presto	radiation dominated	earlier than 10,000 yrs.	abundance of the light elements
andante	matter dominated	later than 10,000 yrs.	growth of galaxies and structure
largo	vacuum dominated (inflation)	day before yesterday	acceleration of the universe

**“For every complex natural phenomenon
there is a simple, elegant, compelling,
wrong explanation.”**

- Tommy Gold

An early particle cosmologist



Erwin Schrödinger

1938-1939: Graz \longrightarrow Vatican \longrightarrow Gent, Belgium \longrightarrow Dublin

The proper vibrations of the expanding universe

Erwin Schrödinger (1939)

Introduction:

. . . production or annihilation of matter, merely by expansion [of the universe],... Alarmed by these prospects, I have examined the matter in more detail.”

Conclusion:

“... There will be a mutual adulteration of [particles and antiparticles] in the course of time, giving rise to ... the ‘alarming phenomenon’...”

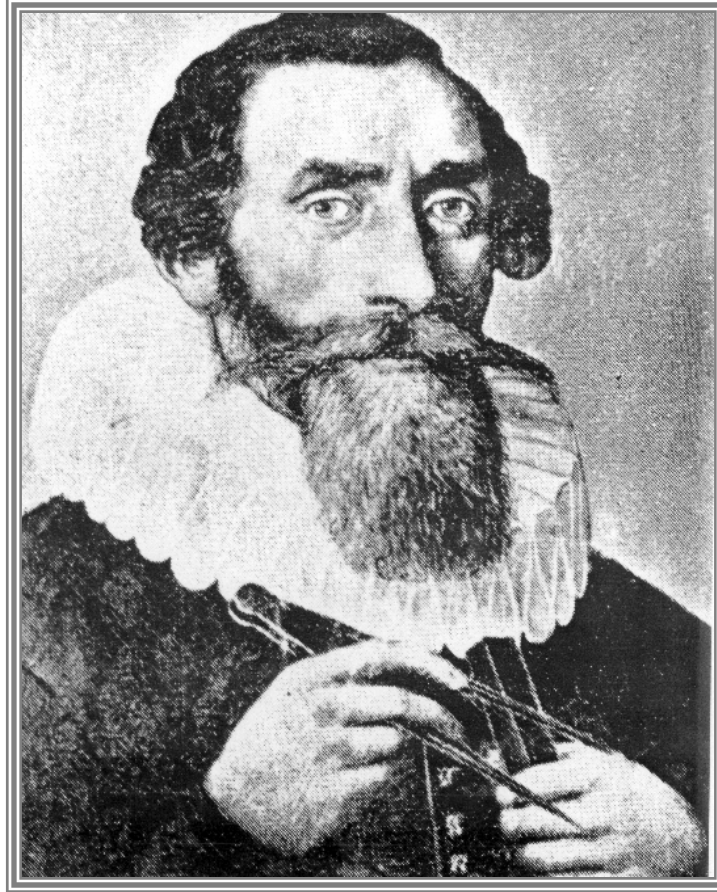
The proper vibrations of the expanding universe

Erwin Schrödinger (1939)

**Creation of a single pair of particles
of undetectably small energy
somewhere in the universe
in the next 14 billion years**

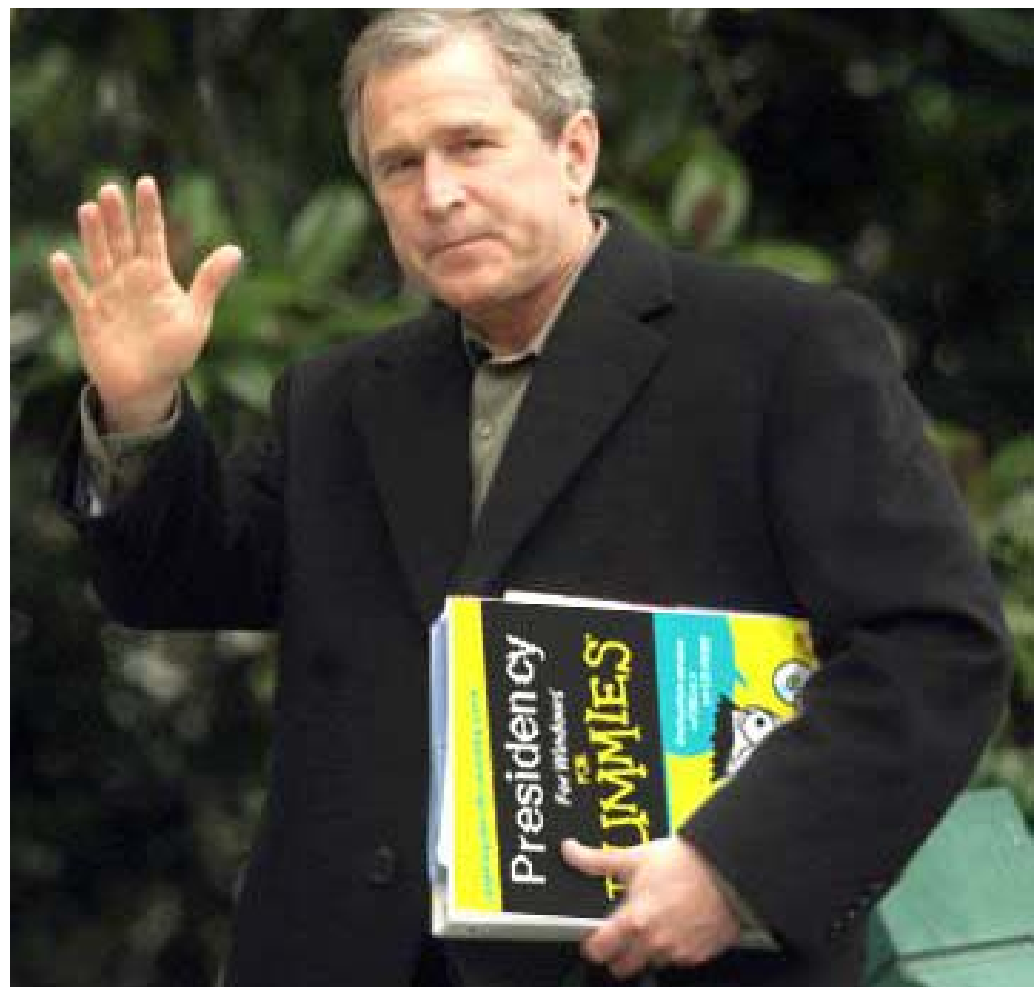
Alarming?

An even earlier Graz cosmologist



“When the storms rage around us, and the state is threatened by shipwreck, we can do nothing more noble than to lower the anchor of our peaceful studies in the ground of eternity.” - *J. Kepler*

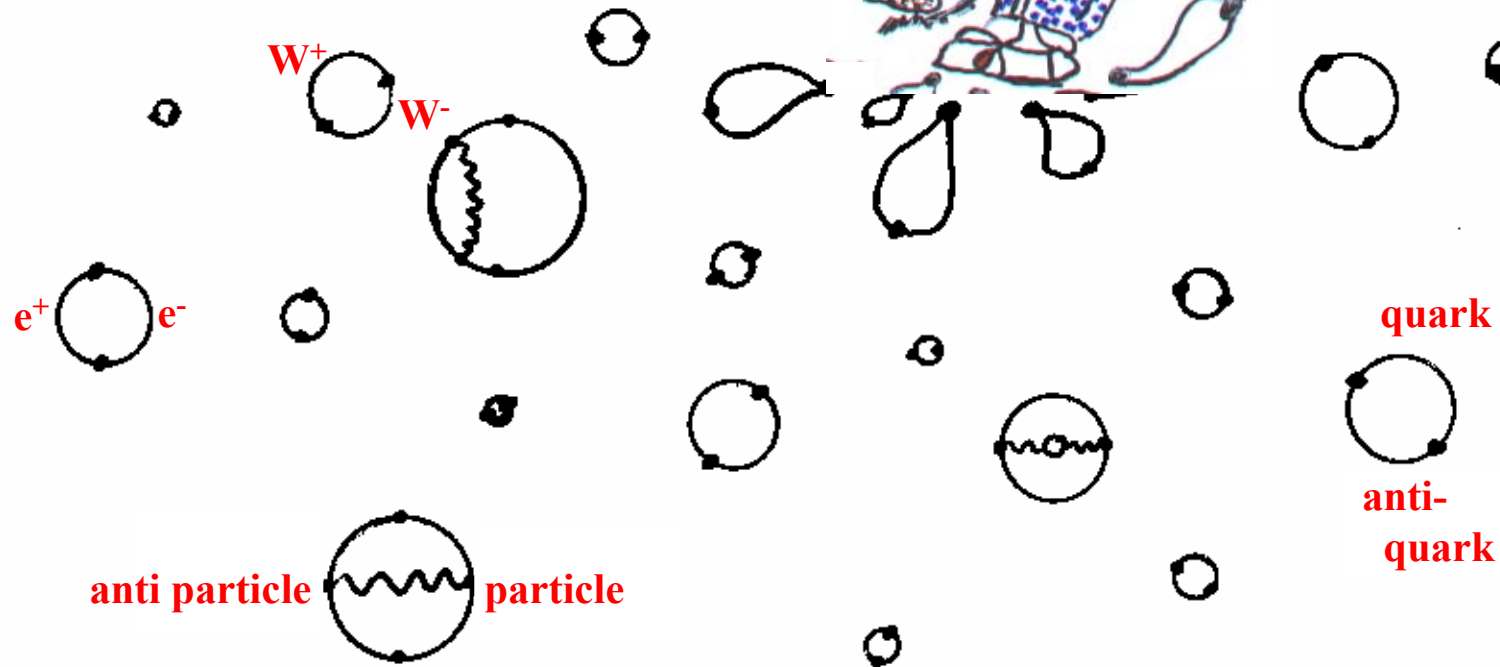
1600-1630: Graz → Prague → Linz → Sagan → Ratisbon



“When the storms rage around us, and the state is threatened by shipwreck, we can do nothing more noble than to lower the anchor of our peaceful studies

The Vacuum

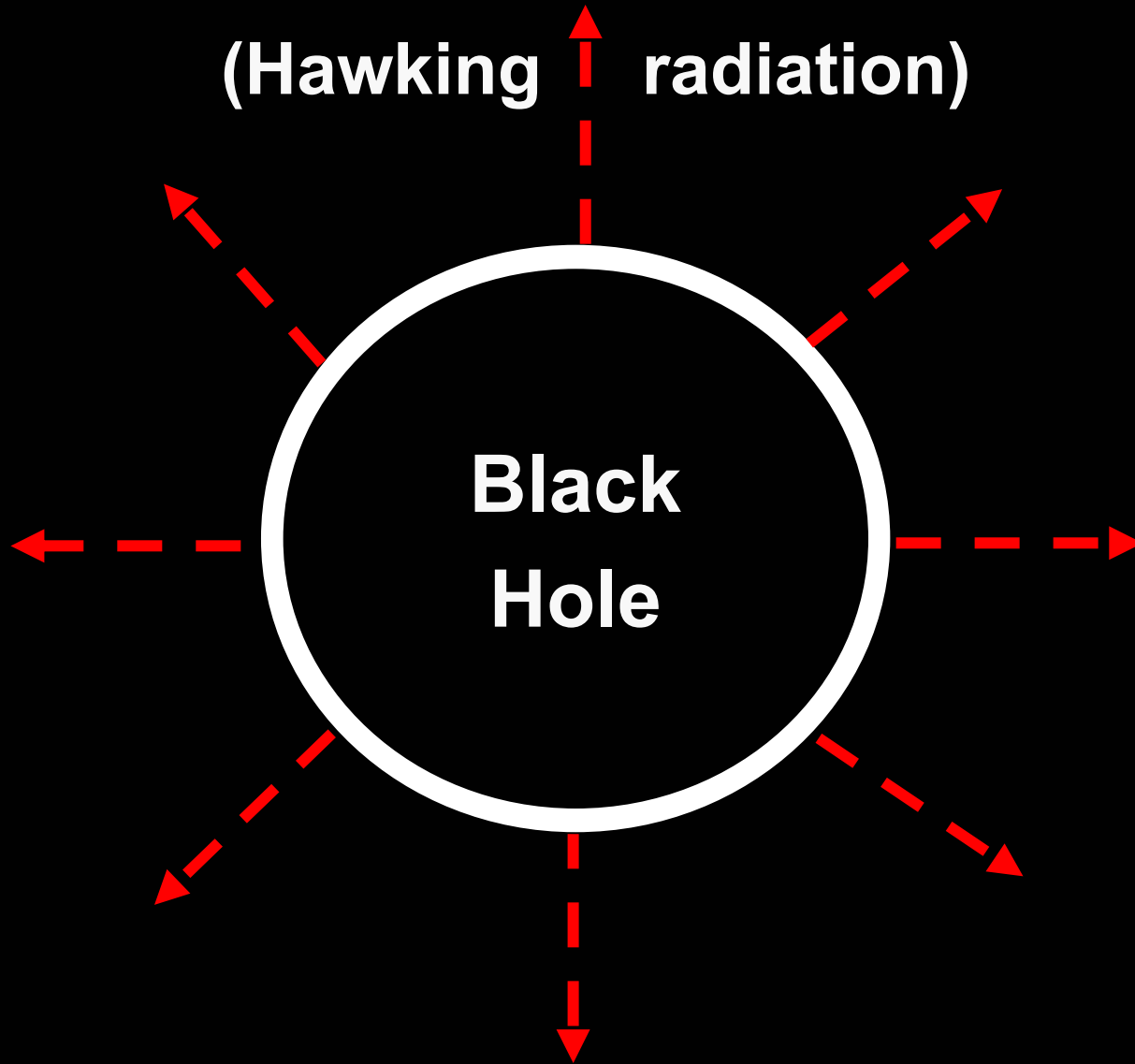
of



Quantum Uncertainty

DISTURBING THE VACUUM

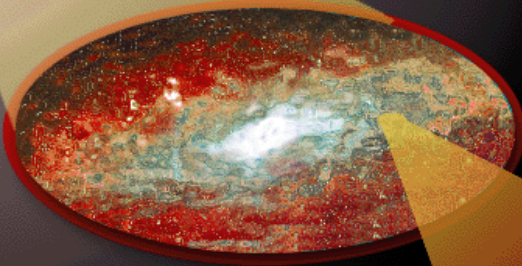
Strong gravitational field \longrightarrow particle production
(Hawking \uparrow radiation)



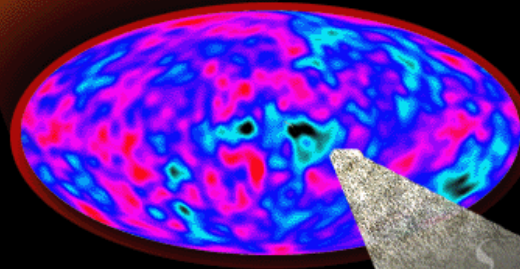
Nothing can change:

BIG BANG

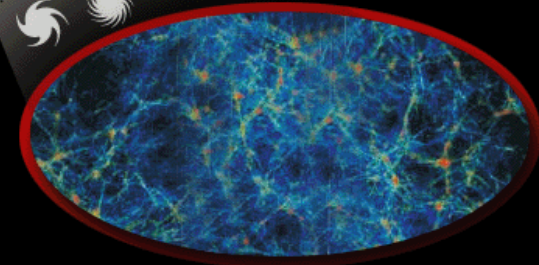
Inflation:
(Big Bang plus
 10^{-34} Seconds)



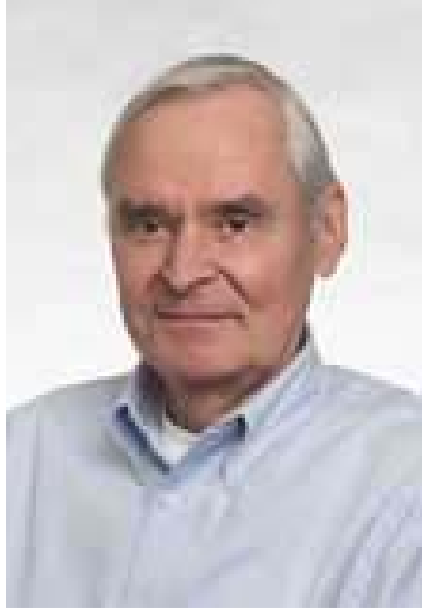
Transparency:
(Big Bang plus
300,000 Years)



Today:
(Big Bang plus
14 Billion Years)



Wilkinson Microwave Anisotropy Probe



David T. Wilkinson
1935-2002

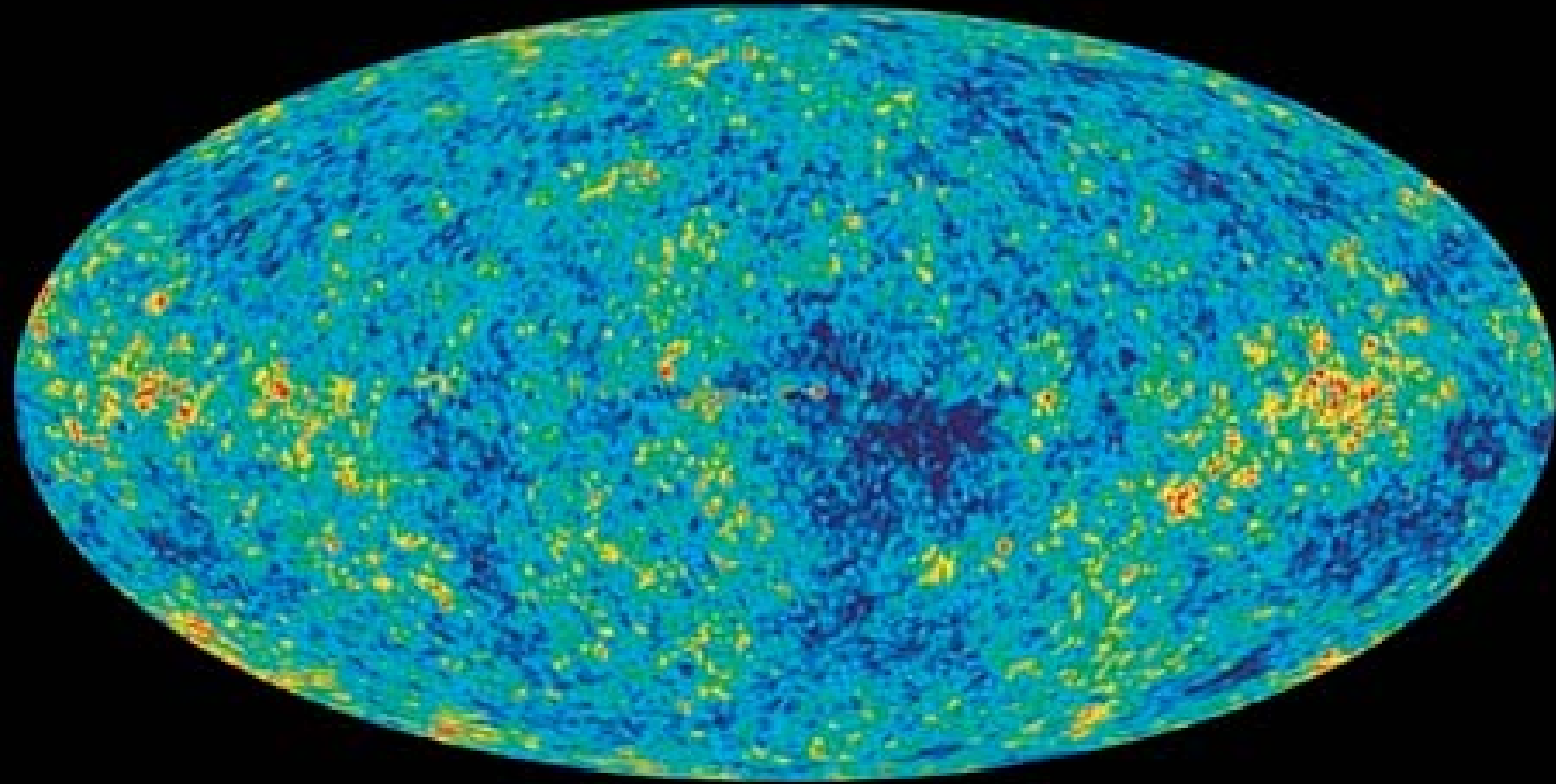


WMAP model



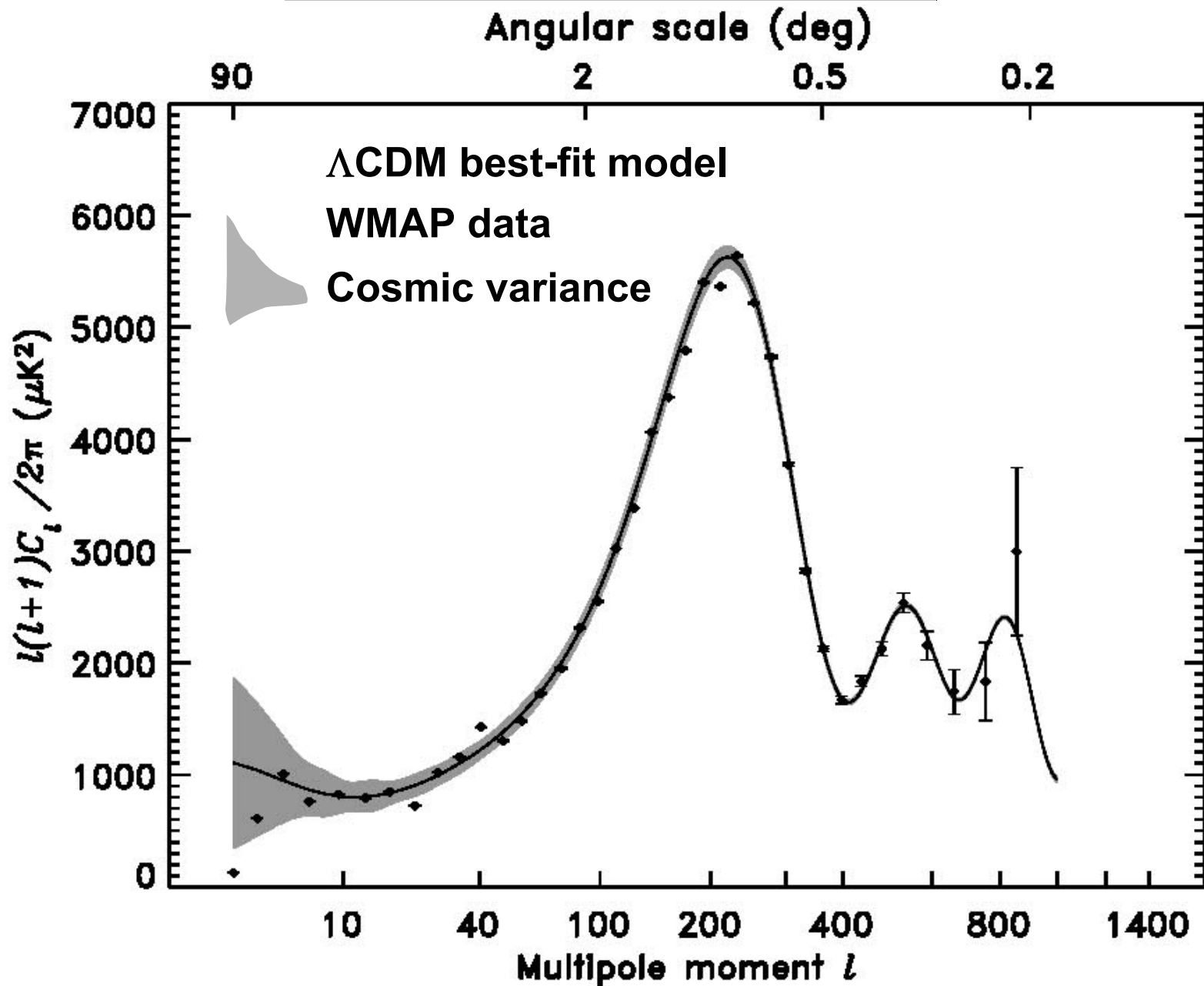
WMAP science team

Quantum uncertainty—inner space



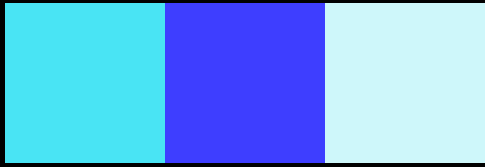
Temperature ripples—outer space

CMB post-MAP



Chicago at night





2°K

3°K

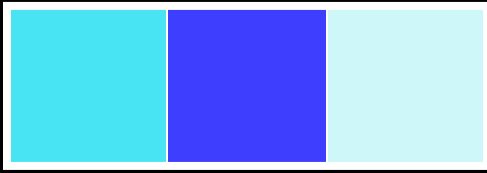
4°K

The microwave sky

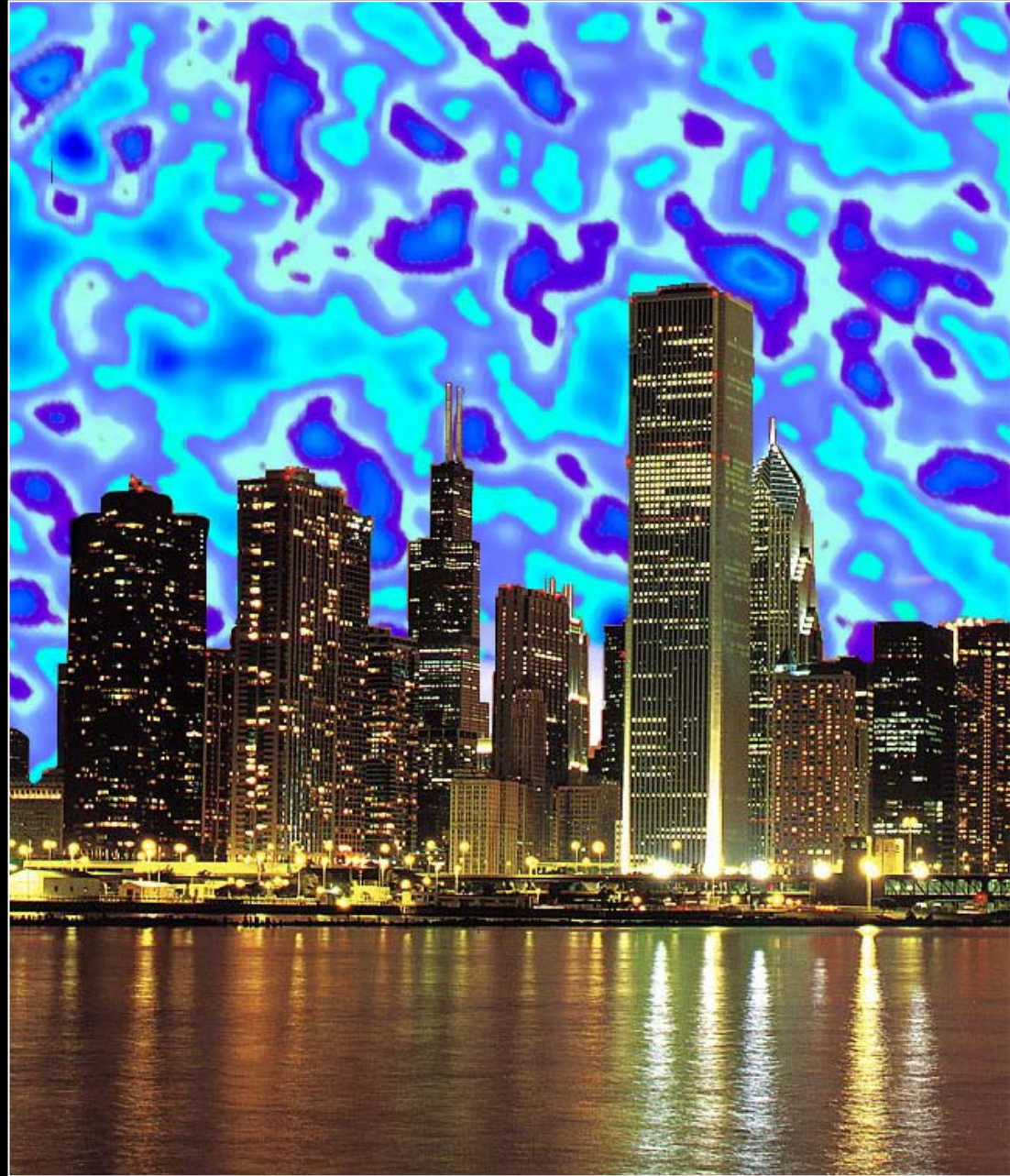
$T = 2.728^{\circ} \text{ K}$

(-454° F)



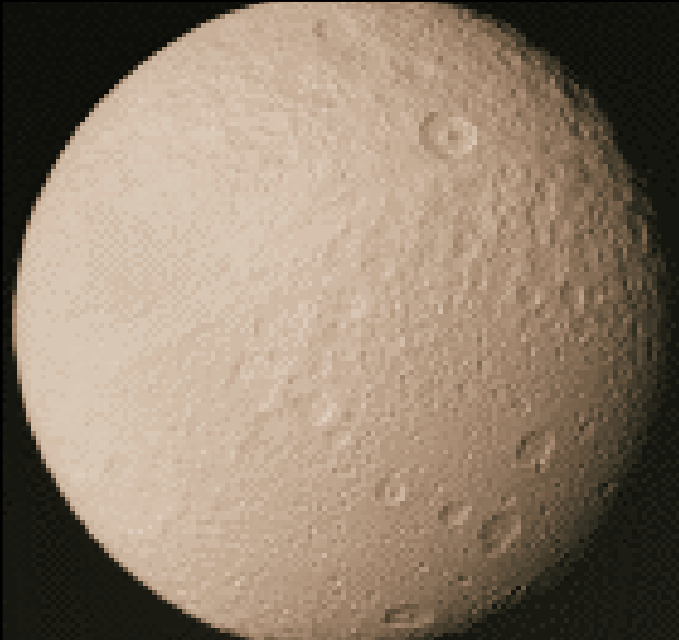


**hot and cold spots
differ by
30 parts
per million**

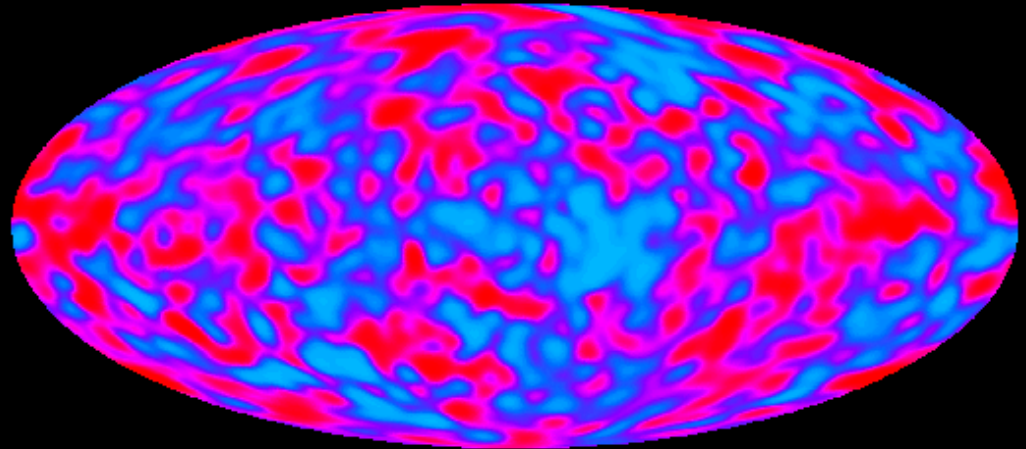


IMPERFECTIONS ARE BEAUTIFUL

Tethys



Background radiation



EVERYTHING IN THE UNIVERSE

MICROWAVE RADIATION PATTERN

SUPERCLUSTERS OF GALAXIES

CLUSTERS OF GALAXIES

STARS

PLANETS

PEOPLE

POODLES

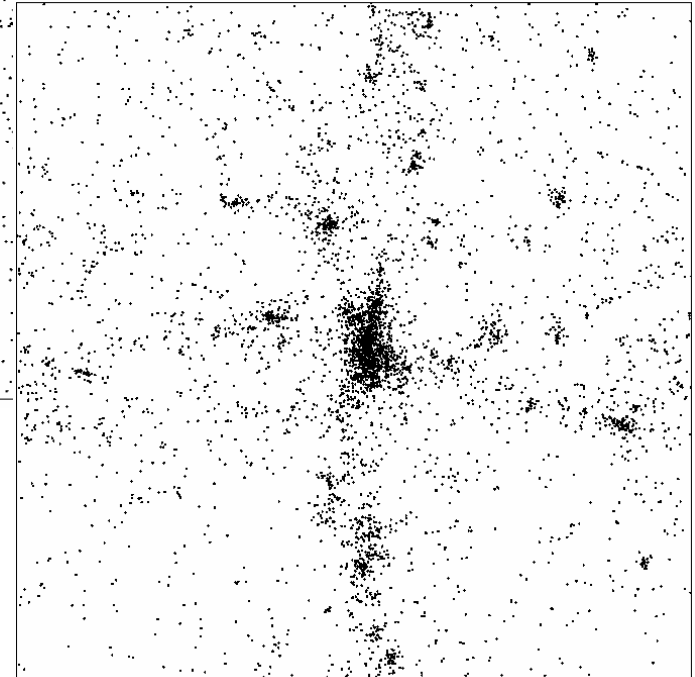
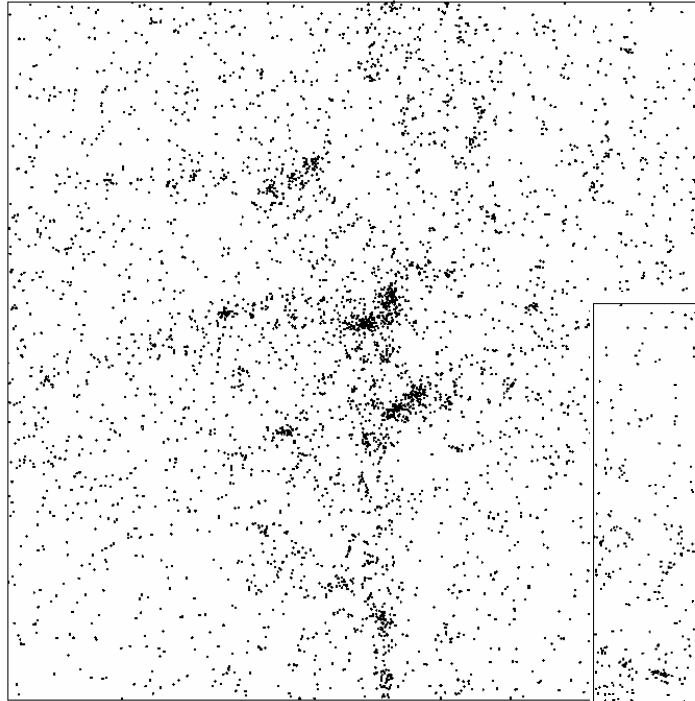
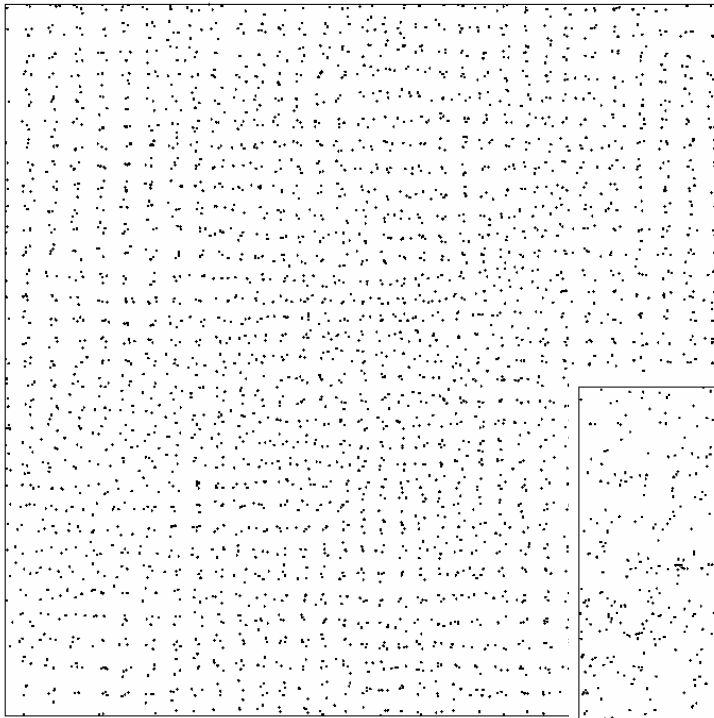
PIGEONS

PETUNIAS

POND SCUM

FROM THE QUANTUM VACUUM!

Seeds of structure



time 

Simulation

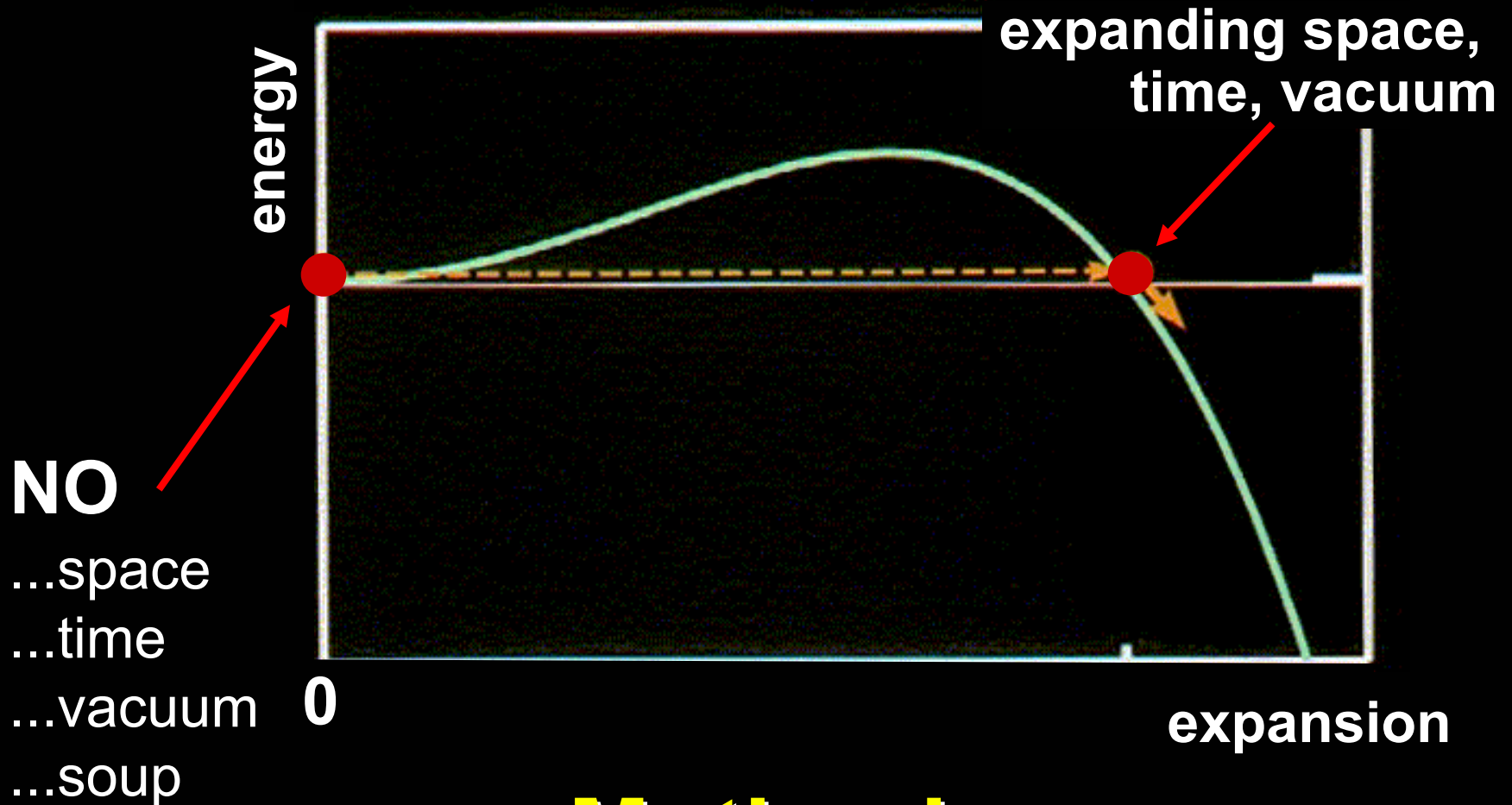
Simulation (simiˈlɪʃən). ME. [a. OF., ad. L. *simulationem*.] 1. The action or practice of simulating, with intent to deceive; false pretence, deceitful profession ME. b. Unconscious imitation 1870. 2. A false assumption or display, a surface resemblance or imitation, *of* something.

Oxford English Dictionary

BEFORE NOTHING ?

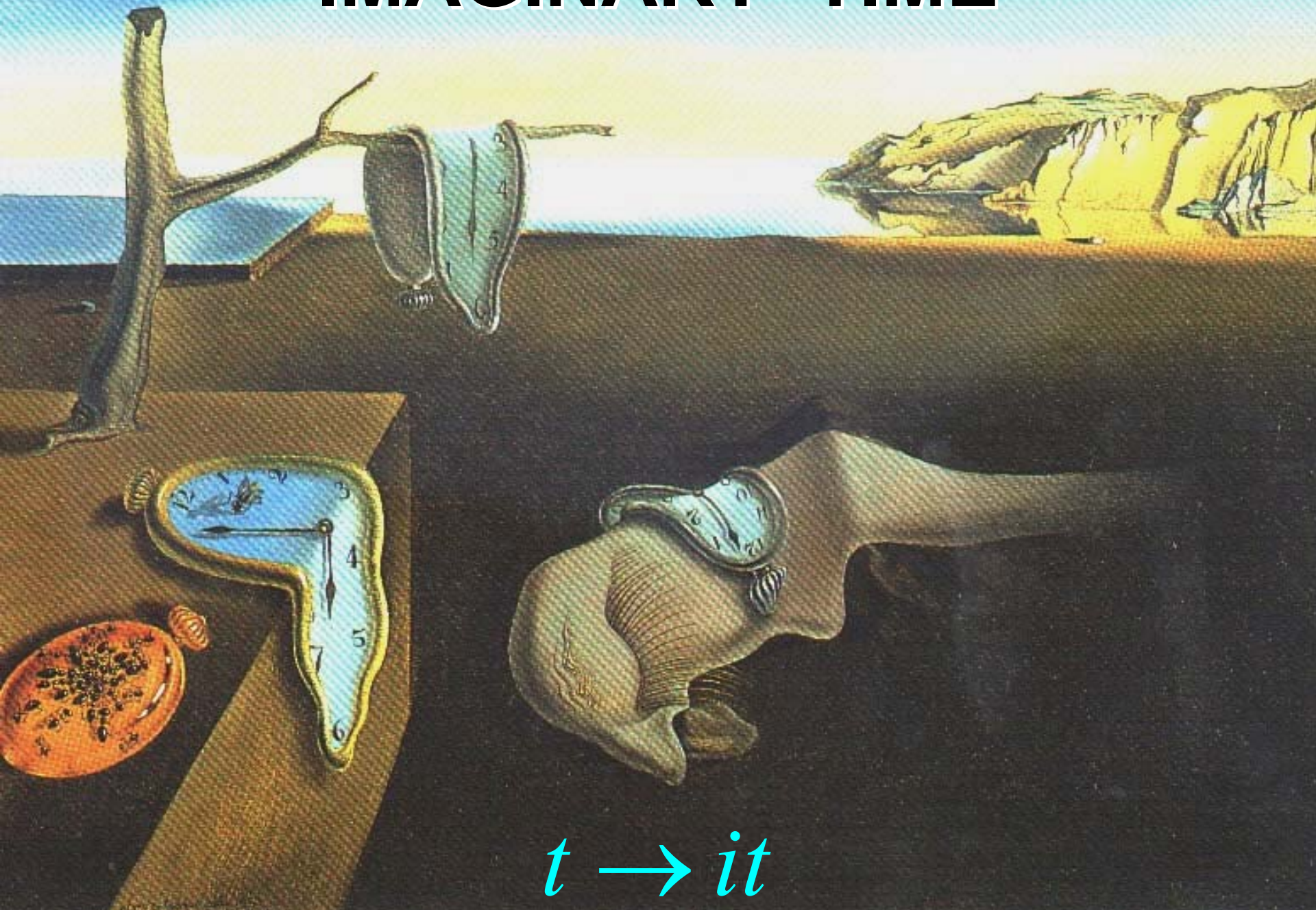
- quantum creation of space, time, vacuum *from less than nothing.*
- nothing is unstable -- emergence of the universe is *inevitable.*

QUANTUM TUNNELING



**Motion in
“IMAGINARY TIME”**

IMAGINARY TIME



$$t \rightarrow it$$

Classical path

Possible quantum paths

